



Constant Resistant at Different Speeds while Pushing a Sled Prompts Different Adaptations in Neuromuscular Timing on Back and Lower Limb Muscles

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Abstract: Resistance training (RT) is commonly used to target specific weakened muscle groups. Among the plethora of methods employed as RT, the current study focused on a sled that provides constant resistance proportional to speed. This study aimed to examine neuromuscular patterns of the lower extremity and trunk muscles in response to pushing a sled with constant resistance at two different speeds. Twenty-six young adults (average age, 23.8) participated in this study. Surface electromyography electrodes were placed on gluteus maximus (GMAX), gluteus medius (GMED), tibialis anterior (TA), gastrocnemius (GA), and erector spinae (lumbar and thoracic) of their dominant leg or side (unilateral at the same side as the dominant lower limb). Neuromuscular timing was collected during four tasks: walking, running, walking-pushing the sled (WP), and running-pushing the sled (RP). All gait activities were repeated twice, with self-selected speed and an equivalent distance of 40 feet. A MANOVA analysis showed that during WP, GMED and GMAX showed more neuromuscular recruitment than leg and trunk muscles when compared to walking. During RP, the thoracic musculature was significantly more involved than any other muscle during running. Based on our findings, we recommend that physiotherapists and trainers use this sled with constant resistance during walking in patients with pelvic or hip weakness. Further, we suggested utilizing the sled in subjects requiring mid-trunk activation at faster speeds, such as fast walking or running.

Keywords: Resistance training, Walking, Pelvic or hip weakness, Muscle groups

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1. Introduction

Resistance training (RT) is a strategy to improve muscle strength and increase muscle mass [1]. Based on the client's needs and muscular group, RT devices can employ assorted tools. In that regard, RT is an essential intervention to promote basic motor skills, such as running and rapid change of direction, among others [2]. Research has shown that two-fifteen to twenty-minute sessions per week can significantly improve muscle torque and decrease injuries [3]. A sled is a type of RT that facilitates walking at different speeds while pushing or towing against resistance. Additionally, compared to body-weight, pulling a sled at approximately 30 percent of a subject's weight shows advantages on the involved musculature [4]. In addition, a sled can engage multiple muscles simultaneously, making this tool more effective in treating large areas or generalizing weakness.

The current study used the XPO trainer sled, which provides constant resistance with constant speed, allowing low-resistance and high-repetition training [5]. This sled showed a faster neuromuscular recruitment in leg musculature as the speed increased [5]. In general, pushing the sled while running causes a reduction in duration due to a quicker neuromuscular recruitment or onset. On the other hand, during walking activities, muscle activation occurs later or is delayed in WP compared to walking tasks, making the constant resistance of the sled valuable to prevent muscle fatigue. Pushing against constant resistance at different velocities can provoke distinct patterns of neuromuscular recruitment speed and peak muscle activation [5,6].

During the Rosario (2020) and Rosario & Mathis (2020) [5,6] studies, distal muscles were isolated using this form of training to study the impact on motor control and coordination [6]. Both investigations above focused only on leg and thigh musculature. Therefore, the effectiveness of a pushing activity (sled) with constant resistance and speed for the proximal musculature (hip muscles) is yet to be investigated. The proposed study examined the activation of thoracic, lumbar, and hip muscles, such as the gluteus, during pushing-walking and pushing-running with the sled. The importance of adding this musculature is based on evidence indicating that individuals with weak erector spinae often experience

low back pain. Although the erector spinae are most often strengthened by performing exercises in the prone or supine position, this position often leads to further injury due to excessive shear forces and compression of the vertebrae [7]; therefore, it is not a universal treatment for all client conditions. Behm *et al.* [7] compared erector spinae activation while running to activation level during calisthenic exercises, such as curl-ups and isometric back extension. Researchers concluded that trunk-stabilizing muscles activated similar to more than calisthenic exercises in the supine or prone position during running activities [7]. Additionally, pelvis stabilizers such as Gmed are at peak activity during the stance phase. During walking and running activities, pelvis stability is crucial for proper body mechanics [8]. For instance, patellofemoral pain is presented when GMed exhibits neuromuscular alterations, such as delayed and shorter activation during gait activities [9].

In conclusion, the current study focused on the impact of RT with the sled on the neuromuscular timing of the gluteus medius (GMed), gluteus maximus (GMax), and back muscles. This research aimed to identify neuromuscular timing patterns on the back and lower limb muscles of young healthy adults while pushing a sled at different speeds. We hypothesized that the proximal musculature (back and gluteal muscles) would be more active or engaged than the distal musculature (gastrocnemius and tibialis anterior) while walking and pushing the sled. This study also speculated that the distal musculature would be more engaged during run push than the proximal musculature.

2. Methods

This study recruited men and females aged 21-40 years by word of mouth from Texas Woman's University (TWU) Dallas and their surroundings. All participants were screened for eligibility based on the inclusion and exclusion criteria. Inclusion criteria included the ability to walk and run without an assistive device, and no injury or surgery of the lower back and leg in the last six months. From there, the eligible participants signed an informed consent form before participating in the study. The TWU IRB approved this study (Protocol # 20091). Once consent was provided, and cardiovascular values were assessed (blood pressure and heart rate), electromyography (EMG) surface electrodes were placed on the respective lower limb and back muscles. The area of the skin was clean with alcohol pads and shaved in preparation of the

EMG surface electrodes. On the dominant side, the EMG surface electrodes were placed on the following muscles: gluteus maximus (GMAX), gluteus medius (GMED), tibialis anterior (TA), gastrocnemius (GA) and thoracic and lumbar regions. In this study, the dominant lower extremity was defined as the leg used to kick a ball.

Gait protocol: This protocol follows a standardized procedure published by utilizing the sled XPO trainer [5]. Rosario and Mathis (2020) [6] stated that this particular sled has the novelty of adapting resistance to speed. Therefore, if sustained constant, the faster the speed, the more continued resistance the sled delivered to the user.

The gait protocol began with a 40 ft walkway warm-up walk of 40 ft, and once the participants completed the "warm up" walk, they went through four protocols: the walking protocol, the walking push (WP) protocol, the run protocol, and the run push (RP) protocol. All four tasks had the same distance, 40 ft even-walkway marked by two orange cones (1 at the start and 1 at the end). Each gait activity was repeated twice, with a two-minute break between the tasks. For the W and WP protocols, the participants were instructed to walk at a self-selected normal pace. On the other hand, participants were instructed to run as fast as possible for the R and RP protocols. EMG data were collected during the totality of the 40 ft walkway during all four tasks, and stopped once the participant reached 40 ft marked by a cone; the investigator then turned off the EMG, and the participant stopped walking. During the 1) W protocol, participants were instructed to walk 40 ft without using the XPO trainer. With the 2) WP protocol, the participant was instructed to walk 40 ft, pushing the XPO trainer. Then, for the 3) R protocol, the participant was instructed to sprint 40 ft without using the XPO trainer. Lastly, during the RP protocol, the participant was instructed to sprint 40 ft,

pushing the XPO trainer. After each task, participants were instructed to return to their initial cone. When applicable, a research member returned the XPO trainer.

2.1 Data Analysis

The current investigation used electromyography (EMG recorded neuromuscular data) operating a surface electrode system (Delsys, Inc. Boston, MA, USA) and processed using EMG analysis for all muscles. The EMG activity of the gluteus maximus, gluteus medius, thoracic spine, lumbar spine, tibialis anterior, and gastrocnemius muscles was collected at 1,000 Hz with the electrodes placed conforming to standardized recommendations [10,11]. Three activation points of the EMG trace for each muscle during all trials were identified. The various data points covered the time before muscle activation (onset), at maximal peak activation (TP), after activity ended (decay), and the duration of the activity. The present study used SPSS (version 25) with a MANOVA analysis to compare the means for neuromuscular-time variables with and without pushing. In this study, we consider a p-value of < 0.01 significant.

3. Results

Table 1 depicts the demographic factors of the subjects in the present investigation. Twenty-six young adults aged 23.8/- 3.1 enrolled in this study (5 male and 21 female).

Tables 2a, 2b, and 2c present data for W and WP for all the muscles of interest. A significant difference ($P < 0.01$) was identified with an increase in the length of activation for the GMax onset, time to peak, decay, and duration in WP compared to walking. Another significant difference ($P < 0.01$) was identified as an increase in the length of activation of the GMed for onset, decay, and duration.

Table 1 Demographic information and Inclusion Criteria Data

Characteristics	Mean and SD
Age	23.8 +/- 3.1
Gender	Male = 5 Female = 21
Leg Dominance	R = 23 L = 3
Height (inches)	66.5 +/- 3.9

Weight (pounds)	139.9 +/- 20.7
Inclusion Criteria Data	
Characteristics	Mean and SD
BMI (kg/m ²)	21.9 +/- 3.2
Heart Rate (bpm)	77.4 +/- 15.1
Systolic BP (mmHg)	120.9 +/- 14.6
Diastolic BP (mmHg)	80.6 +/- 9.8
Sat O2 (%)	99 +/- .01
SD: standard deviation, BP: Blood Pressure, bpm:beat per minute	

Table 2a Comparisons of EMG timing (seconds) for GMAX and GMED among tasks. Results of a MANOVA were performed comparing walk versus walk push. The significance level was set at $p \leq 0.01$.

Glut Max	Walk Means and SD	Walk Push Means and SD	P-value
Onset	.5656 +/- .1327	.8135 +/- .1632	0.01
Time to peak	.2399 +/- .0577	.2988 +/- .0783	0.01
Decay	.3257 +/- .1027	.5148 +/- .1534	0.01
Duration	.5656 +/- .1327	.8135 +/- .1632	0.01
Glut Med	Means and SD	Means and SD	P-Value
Onset	.6273 +/- .1691	.8809 +/- .1562	0.01
Time to peak	.2617 +/- .0935	.3251 +/- .0934	0.05
Decay	.3657 +/- .1301	.5558 +/- .1363	0.01
Duration	.6274 +/- .1691	.8809 +/- .1562	0.01
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 2b Comparisons of EMG timing (seconds) for TA and GA among tasks. Results of a MANOVA were performed comparing walk versus walk push. The significance level was set at $p \leq 0.01$.

Tibialis Anterior	Walk Means and SD	Walk Push Means and SD	P-value
Onset	.7432 +/- .1463	.8718 +/- .2558	0.05
Time to peak	.4377 +/- .1276	.5224 +/- .191	0.07
Decay	.3055 +/- .0712	.3494 +/- .1238	0.14
Duration	.7432 +/- .1463	.8718 +/- .2558	0.05

Gastrocnemius	Means and SD	Means and SD	P-Value
Onset	.6826 +/- .1386	.7354 +/- .1166	0.16
Time to peak	.3865 +/- .0917	.4127 +/- .0911	0.33
Decay	.2961 +/- .0927	.3228 +/- .0901	0.31
Duration	.6826 +/- .1386	.7354 +/- .1166	0.16
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 2c Comparisons of EMG timing (seconds) for Lumbar and Thoracic among tasks. Results of MANOVA were performed comparing walk versus walk push. The significance level was set at $p \leq 0.01$.

Lumbar	Walk Means and SD	Walk Push Means and SD	P-value
Onset	.2384 +/- .1232	.1649 +/- .7485	0.64
Time to peak	.1018 +/- .0448	-.0171 +/- .6902	0.40
Decay	.1366 +/- .0860	.1820 +/- .1202	0.14
Duration	.2384 +/- .1232	.1649 +/- .7485	0.64
Thoracic	Means and SD	Means and SD	P-Value
Onset	.1581 +/- .5263	.1726 +/- .7034	0.94
Time to peak	.1708 +/- .1031	.1702 +/- .3412	0.99
Decay	-.0127 +/- .5558	.0024 +/- .6070	0.93
Duration	.1581 +/- .5263	.1726 +/- .7034	0.94
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 3a Comparisons of EMG timing (seconds) for GMAX and GMED among tasks. Results of a MANOVA were performed comparing run versus run push. The significance level was set at $p \leq 0.01$.

Glut Max	Run Means and SD	Run Push Means and SD	P-value
Onset	.4800 +/- .8113	.5176 +/- .0776	0.11
Time to peak	.2537 +/- .0694	.2899 +/- .0665	0.07
Decay	.2264 +/- .0563	.2277 +/- .0583	0.94
Duration	.4800 +/- .0811	.5176 +/- 0.776	0.11
Glut Med	Means and SD	Means and SD	P-Value
Onset	.3883 +/- .3584	.4877 +/- .0550	0.19
Time to peak	.1697 +/- .3431	.2490 +/- .0563	0.27
Decay	.2185 +/- .0562	.2388 +/- .0647	0.25

Duration	.3883 +/- .3584	.4877 +/- .0550	0.19
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 3b Comparisons of EMG timing (seconds) for TA and GA among tasks. Results of a MANOVA were performed comparing run versus run push. The significance level was set at $p \leq 0.01$.

Tibialis Anterior	Run Means and SD	Run Push Means and SD	P-value
Onset	.4988 +/- .1318	.5222 +/- .1489	0.57
Time to peak	.2524 +/- .0890	.2604 +/- .1050	0.78
Decay	.2464 +/- .0743	.2618 +/- .0906	0.52
Duration	.4988 +/- .1318	.5222 +/- .1489	0.56
Gastrocnemius	Means and SD	Means and SD	P-Value
Onset	.3459 +/- .5753	.5392 +/- .0512	0.11
Time to peak	.1304 +/- .5609	.3294 +/- .0480	0.09
Decay	.2155 +/- .0470	.2098 +/- .0274	0.60
Duration	.3459 +/- .5753	.5392 +/- .0512	0.11
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 3c Comparisons of EMG timing (seconds) for Lumbar and Thoracic among tasks. Results of MANOVA were performed comparing run versus run push. The significance level was set at $p \leq 0.01$.

Lumbar	Run Means and SD	Run Push Means and SD	P-value
Onset	.2353 +/- .1675	.2603 +/- .0799	0.52
Time to peak	.1153 +/- .0621	.1466 +/- .0662	0.09
Decay	.1200 +/- .1150	.1138 +/- .0446	0.81
Duration	.2353 +/- .1675	.2603 +/- .0799	0.51
Thoracic	Means and SD	Means and SD	P-Value
Onset	.2062 +/- .0612	.2921 +/- .0810	0.001
Time to peak	.0955 +/- .0365	.1395 +/- .0374	0.001
Decay	.1108 +/- .0387	.1526 +/- .0668	0.01
Duration	.2062 +/- .0612	.2921 +/- .0810	0.001
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Tables 3a, 3b, and 3c exemplify the comparisons of R and RP for all the muscles of interest. The thoracic musculature was the only muscle group

that showed a significant increase ($P < 0.01$) in the activation time of the onset, time to peak, decay, and

duration while pushing the sled compared to running without the sled.

4. Discussion

As mentioned above, the current study intended to recognize neuromuscular timing patterns on the back and lower limb musculature of young healthy adults while pushing a sled at different speeds. This inquiry established two working hypotheses to study the role of this type of sled resistance on muscle neuromuscular activation.

The first hypothesis stated that the proximal musculature (back and gluteal muscle) would be more active or engaged than the distal musculature (gastrocnemius and tibialis anterior) while walking and pushing the sled. The findings of this study showed adaptability in GMax and GMed, but not in back muscles. Therefore, we partially accept our hypothesis. GMax took longer to activate and reach peak activity during WP. Additionally, GMax had a longer decay and therefore increased the duration of activity compared to W. The above findings suggest an added benefit of pushing this type of sled in further engaging proximal lower limb musculature when WP. During WP, gait parameters are modified in response to proximal muscles adapting by engaging in aiding in the stability of the pelvis and trunk. Prior research using the Sled XPO Trainer has indicated that pushing the sled causes a decrease in stride length, velocity, and cadence compared to not pushing the sled [6]. This gait parameter difference increases the time the participants spent on double-limb support, which explains the neuromuscular pattern observed in our results. For instance, during the stance phase, pelvic stabilizers such as GMed are recruited [8]; an increased period in the support phase will also require prolonged activation. Since pushing the sled is provoking faster and prolonging muscle recruitment on the gluteal muscles, the authors recommend using the sled when one or both of these muscles are weak, but also not contracting in a normal pattern. Wilson (2011) [9] pointed out that an altered recruitment pattern of the Gmax and Gmed could be the reason for the knee pain presented in their study participants. Future studies could compare conventional treatment and ale activities in subjects with diverse hip and knee pathologies.

Another important outcome of the current study was that trunk muscles were constantly engaged at the same level during walking activities, followed by lower extremity muscles, which adapted differently

when speed and amount of resistance changed. Comparable to the above discoveries, Y.J. Lee revealed in their research a heightened activation of the trunk and lower extremity musculature while propelling an object [12]. Both outcomes indicate that trunk musculature steadies the vertebra in pushing tasks. Another likely interpretation is the irregular movements related to poor pelvic control during activities that compel spine support [13]. Therefore, pelvic control is essential to spine stability during dynamic trunk movements, and compels a combination of spine and pelvis strengthening programs [13]. Based on the results, the present examination reinforces the understanding that lower limb musculature, such as the gluteus muscles, contributes to trunk stability. Since the participants held on to the handles of the sled while pushing, the upper part of the trunk was stable, compared to the lower portion. These previous remarks suggest that gluteal muscles are responsible for the pelvis and lower back stability while pushing the sled. We recommend prospective studies explore the impact of sled compared to conventional trunk exercises in groups with diverse trunk and hip diagnoses. Nevertheless, the authors recommend utilizing the sled in pelvic and lower limb weakness, since walking while pushing the sled promotes an increase in muscle recruitment.

Our second hypothesis stated that the distal musculature would be more engaged during run push than the proximal musculature. The results showed neuromuscular adaptability in the thoracic musculature while RP sled. Therefore, we rejected our previous assumption. The thoracic musculature had a longer decay, and therefore increased the duration of activity during RP compared to R. Since the upper limbs were stable, holding on to the sled handles, these previous findings suggest that prolonged activation of the thoracic muscle is required to stabilize the thoracic spine for expansion of the thoracic cage, while increasing the effort to breathe while RP. In a study by Zoffoli *et al.* in 2016 [14], they identified that during pole walking, when compared to walking, the trunk muscles had a higher engagement activity to offset the pole forces and increase the stride length of the participant. It was also found that the speed of the treadmill with walking and pole walking affected the muscle activity of the trunk, and that pole walking requires increased engagement and control of the trunk muscles [14]. The current study examined the timing data of the trunk musculature, not the amplitude, making the inability to compare the percentage of muscle activation a limitation of this

study. Similar to Rosario *et al.* (2021) [11], we recommend comparing the percentage of muscle amplitude and the maximal timing of said activity in trunk musculature. Further, we propose utilizing the sled in those participants that require activation of the thoracic region or with low back pain. Engaging in activity that increases the activity of the lumbar region could further stimulate pain, and therefore is not ideal. Activities promoting other back regions, such as the thoracic spine, could be more beneficial for back treatment. Although this previous notion is a suggestion, future studies should explore the impact of an exercise program and its advantages on the lumbar/thoracic region using a sled.

5. Conclusion

This investigation intended to determine patterns in muscle time activation while pushing a constant resistant sled in young, healthy adults. The current examination highlights the increased muscle recruitment varieties for proximal musculature related to distal muscles. Additionally, the thoracic muscles increase muscle recruitment at higher speeds while moving the sled. This report provides broader evidence of hip and lower limb muscle variations while pushing an adaptable resistant sled. The previous knowledge can help design interventions conformed to the client-unique needs. For instance, those with hip pathology or stability impairment will benefit more than those with distal lower extremity injury during self-selected speeds. One limitation of this inquiry is that subjects were asked to walk or run at their selected speed. Therefore, the sled yielded different resistance while pushing. As a proposed consideration, investigators should seek into the impact of this distinct type of sled with a control cadence or speed. One last statement, we advocate researchers and physical therapists to adopt the XPO sled trainer as an adjunct for hip pathologies during WP and trunk weaknesses during RP.

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Informed Consent

The participant gave signed consent for this study

Ethics approval

IRB approval TWU protocol # 20091

Authors Contribution

"MR and MW were involved in planning and supervised the work. MR, KK and JM performed the data collections. MR processed the data, performed the analysis, drafted the manuscript and designed the tables. All authors helped interpret the results and worked on the manuscript. All authors discussed the results and commented on the manuscript. MR, KK and JM contributed to the design and implementation of the research, the analysis of the results, and the writing of the manuscript."

Availability of data and material

No additional data are available.

Conflict of interest

The authors declare that they have no conflict of interest.

Does this article screened for similarity?

Yes

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